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THE EFFECT OF DEAD RISE UPON THE HIGH-ANGLE PORPOISING
CHARACTERISTICS OF TWO PLANING SURFACES IN TANDEM

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ADVANCE RESTRICTED REPORT

THE EFFECT OF DEAD RISE UPON THE HIGH-ANGLE PORPOISING
CHARACTERISTICS OF TWO PLANING SURFACES IN TANDEM

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SUMMARY

Porpoising tests were made of three rudimentary models, each composed of two V-bottom planing surfaces in tandem and fitted with a tail plane. The upper and lower branches of the upper trim limit of stability were determined for three angles of dead rise and for two depths of step. The results showed that the upper trim limits are markedly raised by an increase in angle of dead rise from 15° to $22\frac{1}{2}^\circ$ but are much less affected by an increase from $22\frac{1}{2}^\circ$ to 30° .

The effect of the wing on recovery from the high-angle type of porpoising is discussed to show the importance in tests of specific designs of correctly simulating the slope of the wing lift curve, particularly near the stall where the slope changes rapidly.

INTRODUCTION

Conventional methods of stability analysis have been ably extended by Perring and Glauert (reference 1) to the problem of porpoising. Their work was restricted in scope by the necessity of assuming idealized cases of flat planing plates, singly and in tandem, and of making rough assumptions regarding the derivatives. Further developments (references 2 and 3) of the work of Perring and Glauert have been successful in a treatment of the low-angle type of porpoising - a type that is mainly concerned with the forebody. The efforts to establish a theoretical understanding of the high-angle type of porpoising, in which both the forebody and the afterbody are involved, have been less successful.

The present investigation of the high-angle type of porpoising was carried out to isolate, insofar as appeared practicable, the effect of dead rise, one of the variables known to have an important effect in planing phenomena on the upper and lower branches of the upper trim limit of stability. Porpoising tests were made of models composed of two planing surfaces in tandem without chine flare, warp, or curvature and with a horizontal tail surface having a controllable elevator. The limits for three different angles of dead rise were obtained at a series of constant speeds and constant loads to make the data more amenable to analysis than the data customarily obtained from tests of specific designs.

MODELS AND TOWING APPARATUS

A sketch of the apparatus is given as figure 1. The arrangement, except for the addition of an afterbody, is similar to that described in reference 3. Three models having angles of dead rise of 15° , $22\frac{1}{2}^\circ$, and 30° , respectively, were used. The forebody and afterbody of each model are V-type planing surfaces without chine flare. The keel of each forebody is straight for a distance of 36 inches forward of the step and fairs into a bluff bow with a developable bottom. The plan form is shown in figure 2. Each afterbody has a straight keel inclined at an angle of 7° to the keel of each forebody and has a plan form given by a third-degree equation having the constants listed in figure 2.

Each model was towed from a staff free to move vertically and was free to rotate about the pivot point that was made the center of gravity by ballast weights m_3 , m_4 , and m_5 . The ballast weights m_1 and m_2 were used to adjust the total mass of each system moving vertically. The moment of inertia of each model about its center of gravity was made approximately 6.5 slug-feet square, a typical scale value for a flying boat. The position of the center of gravity was approximately $2\frac{1}{4}$ inches forward of the step and $16\frac{1}{4}$ inches above the keel on a line inclined about 8° forward of a vertical line through the step.

The tail plane is an airfoil of rectangular plan form having an NACA 0015 section and an aspect ratio of

3.42. Its area is 492 square inches and its moment arm to the quarter-chord point is approximately 64 inches. The chord of the elevator is 48 percent of the total chord.

TEST PROCEDURE

Each model was towed free to trim and to rise at a series of constant speeds and constant loads. One branch of the upper trim limit of stability was obtained by manipulating the elevator to increase the trim gradually from the region of stable trims until porpoising started; the boundary between the stable and the unstable regions was designated the upper branch. The method of determining the lower branch customarily used at the NACA tanks (reference 4) is to trim the model high enough to start porpoising and then to lower the elevator gradually until the model recovers and runs stably; the trim at which porpoising suddenly stops is a point on the lower branch of the upper limit. In the present tests without a wing, however, this method could not be used in determining the lower branch because recovery from porpoising was not obtained in the usual way. The lower branch was therefore determined in an arbitrary manner that is generally similar to the method employed at the British R.A.E. tank (reference 5), where the model was towed at constant speed and with various fixed positions of the elevator. Whenever the model appeared to be stable, it was momentarily disturbed in trim about 2° and then allowed either to return to equilibrium or to porpoise. At each speed observations were made to determine the maximum trim before disturbance at which the model would not porpoise after the disturbance.

RESULTS AND DISCUSSION

Trim limits of stability.— Trim limits obtained in the tests are shown in figure 3, in which the upper and lower branches are plotted as critical trim against speed for five loads and for two depths of step. The effect of dead rise is shown more clearly in figures 4 and 5, which were derived from figure 3. An increase in angle of dead rise from 15° to $22\frac{1}{2}^\circ$ caused an increase of 2° or more

in both branches of the upper limit at most loads and speeds. An increase in angle of dead rise from $22\frac{1}{2}^{\circ}$ to 30° generally resulted in a small increase in the trim limits at high speeds and a small decrease in the trim limits at low speeds.

An increase of $1/2$ inch (4.7 to 7.8 percent beam) in the depth of step raised the upper branch about $1\frac{1}{2}^{\circ}$ for all angles of dead rise. The change in the depth of step raises the stern post and consequently increases the trim required before the afterbody comes in contact with the wake. The data in reference 4 show that an increase in the upper trim limit is to be expected.

An increase in the depth of step also raised the lower branch but by a greater amount for an angle of dead rise of 30° than for 15° and $22\frac{1}{2}^{\circ}$. This result is best shown in figure 6, in which critical trims are plotted against speed with allowance being made for the increase in wing lift with increase in speed. For this figure an initial load on the water of 150 pounds and a get-away speed of 49.7 feet per second were assumed for the model, and the wing lift was assumed to increase in proportion to the square of the speed without being affected by trim. The lower trim limit, which is for the forebody alone (from data in reference 3), is included to show the approximate range of stable trim for each angle of dead rise. The graphs show that the increase in depth of step caused a much larger increase in the stable range for an angle of dead rise of 30° than of 15° or $22\frac{1}{2}^{\circ}$.

In reference 3 experimental values of the lower trim limit were plotted against planing lift coefficient and the results for simple V-bottoms were, in most cases, nearly independent of the absolute values of load and speed and consequently independent of the Froude number. The analysis of planing phenomena may be simplified for some purposes by the assumption that Froude's law of comparison can be neglected and the two variables, load and speed, can be combined in a planing lift coefficient. The effect of neglecting Froude's law in analyzing the data for high-angle porpoising may be seen in figure 7, in which the critical trims are plotted against the coef-

ficient $\frac{C_A}{C_V^3}$. The load coefficient C_A and the speed

coefficient C_V are defined by the relations

$$C_{\Delta} = \frac{\Delta}{wb^3}$$

$$C_V = \frac{V}{\sqrt{gb}}$$

where

Δ load on the water, pounds

w specific weight of water, pounds per cubic foot

b beam of model, feet

V speed, feet per second

g gravitational acceleration, feet per second per second

The ratio $\frac{C_{\Delta}}{C_V^2}$ is one-half the planing coefficient

$\frac{\Delta}{\frac{1}{2}\rho V^2 b^3}$ where ρ is the density of water in slugs per cubic foot.

In some of the graphs the points for different loads having the same or nearly the same planing coefficient have practically the same upper trim limit, but for many of the remaining graphs the difference in trim is as much as 2° . For example, in figure 7(c), in the graph for the upper branch for 3/4-inch step, points having planing numbers close together do not differ in trim by more than $1/2^\circ$; whereas in figure 7(a), in the graph for the lower branch for 1 1/4-inch step, the difference in trim is as much as 2° . A theoretical study of high-angle propoising would be considerably simplified if Froude's number were neglected, and for such a purpose a dispersion of 2° in the trim limits may be acceptable. In tests of specific designs, however, inaccuracies of 2° would probably be too great to permit the neglect of Froude's law.

The effect of dead rise has been investigated for a specific design at Stevens Institute of Technology and the results are described in reference 6. Detailed

comparisons with the present tests may not be readily made because of differences in the models and methods employed. The general trends noted for the single upper limit in reference 6, however, agree well with those of the upper branch of the upper limit obtained from the present tests of the rudimentary models without a wing.

An interesting characteristic of all the models tested without a wing was that, after upper-limit porpoising was well established, recovery did not follow the application of down elevator. This result is in sharp contrast to the usual behavior of dynamic models having the wing represented and indicates the importance of the wing in recovery from the high-angle type of porpoising by the usual means available to the pilot.

The most obvious effect of the wing during upper-limit porpoising is the change in load on the water with change in trim. The present tests were made with constant load on the water with the result that the slope of the aerodynamic lift curve

$$Z_{\theta} = \frac{\partial Z}{\partial \theta} = 0$$

where

Z lift, pounds

θ angle of trim about lateral axis, degrees

In tests of complete dynamic models, Z_{θ} has a definite value and is made to approximate the full-size value as far as possible by geometric similarity of the wing and flaps. Leading-edge slats are used to prevent premature stalling of the wing at the low Reynolds numbers obtained in the tank tests. As in wind-tunnel tests, the effects of power are difficult to predict and are best simulated by the use of powered propellers.

Tests at Stevens Institute of Technology (reference 6) have indicated that an increase in Z_{θ} from "normal" to "1.5 times normal" eliminates upper-limit porpoising at speeds near get-away. These results are a further indication that the slope of the lift curve near the stall where Z_{θ} is changing rapidly is of importance in the prediction of full-size upper-limit porpoising characteristics.

CONCLUDING REMARKS

Tests of the three planing surfaces showed that:

Dead rise had an appreciable effect on the high-angle porpoising characteristics within the range of angles of dead rise currently used on seaplanes. The upper trim limits were markedly raised by an increase in angle of dead rise from 15° to $22\frac{1}{2}^{\circ}$ but were less affected by an increase from $22\frac{1}{2}^{\circ}$ to 30° ; the lower trim limit of stability was also raised by an increase in dead rise. The net effect of an increase in dead rise was to shift the stable range of trim to higher values without greatly altering the range between the upper limits and the lower limit.

The wing had an important influence on the ability to recover from high-angle porpoising by reducing the trim. In model tests intended to predict the behavior of a specific design, the lift and the change in lift with trim should be reproduced as well as is possible within the limitations imposed by scale effect and by the difficulty of estimating the lift curve of the full-size seaplane.

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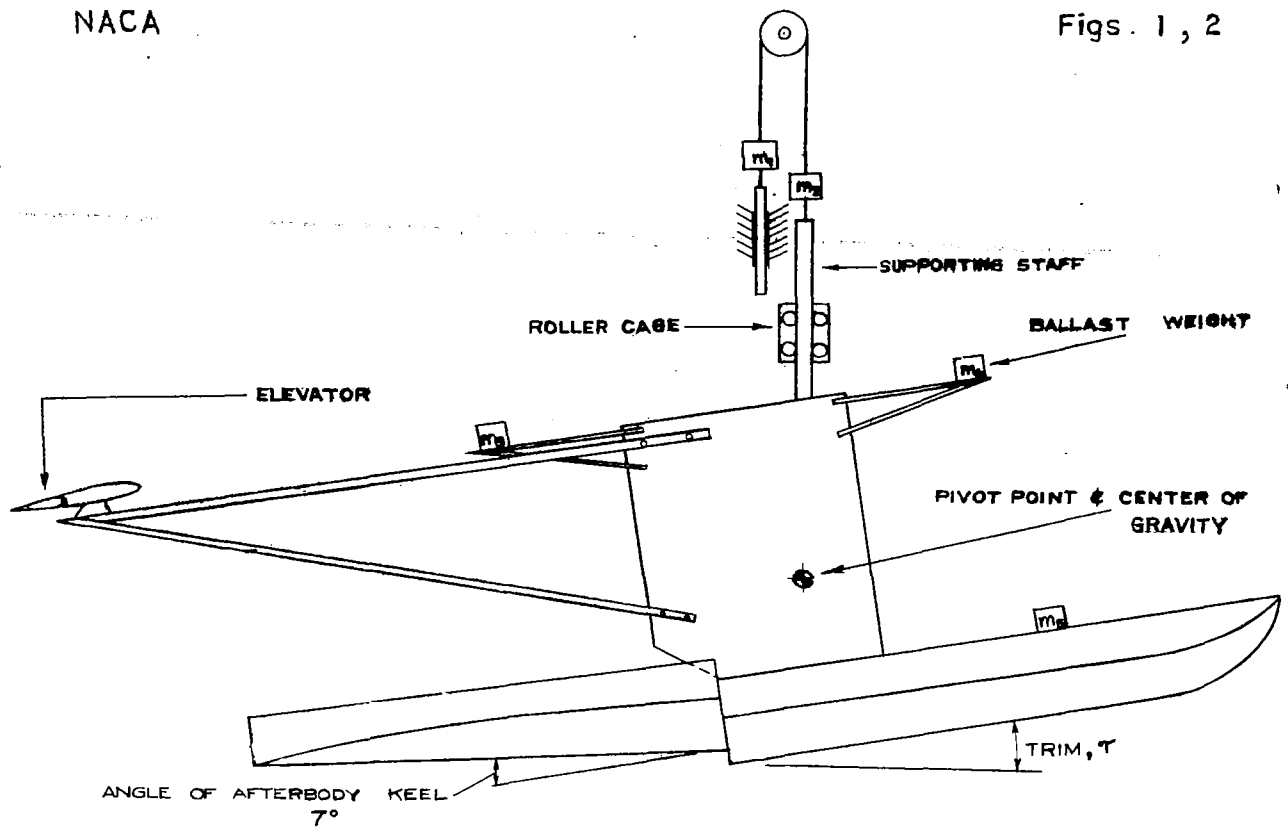


FIGURE 1.- SKETCH OF MODEL AND TOWING ARRANGEMENT

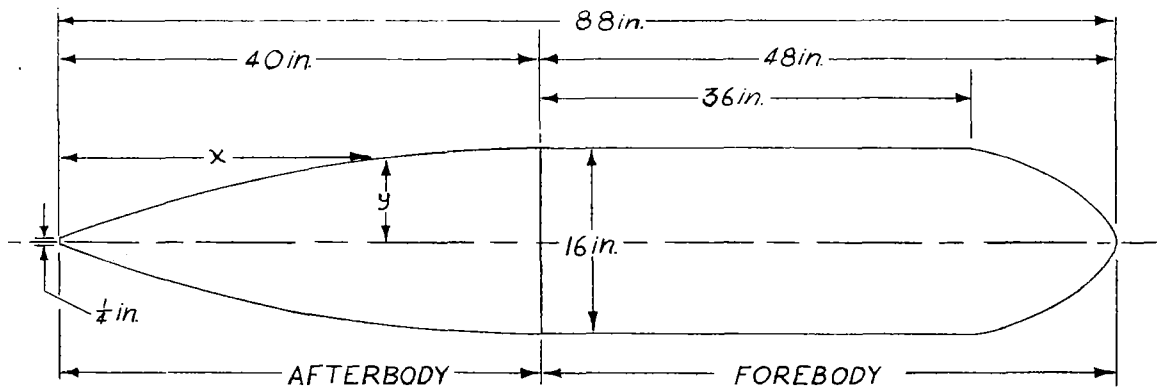
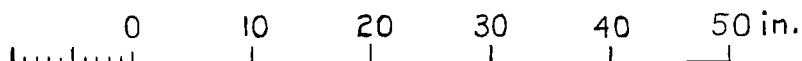


FIGURE 2.- PLAN FORM OF PLANING PLATES.

Equation of afterbody curve: $y = ax^3 + bx^2 + cx + d$

$$a = -3.875 \times 10^{-6} \quad c = 0.3876$$

$$b = -4.613 \times 10^{-3} \quad d = 0.125$$



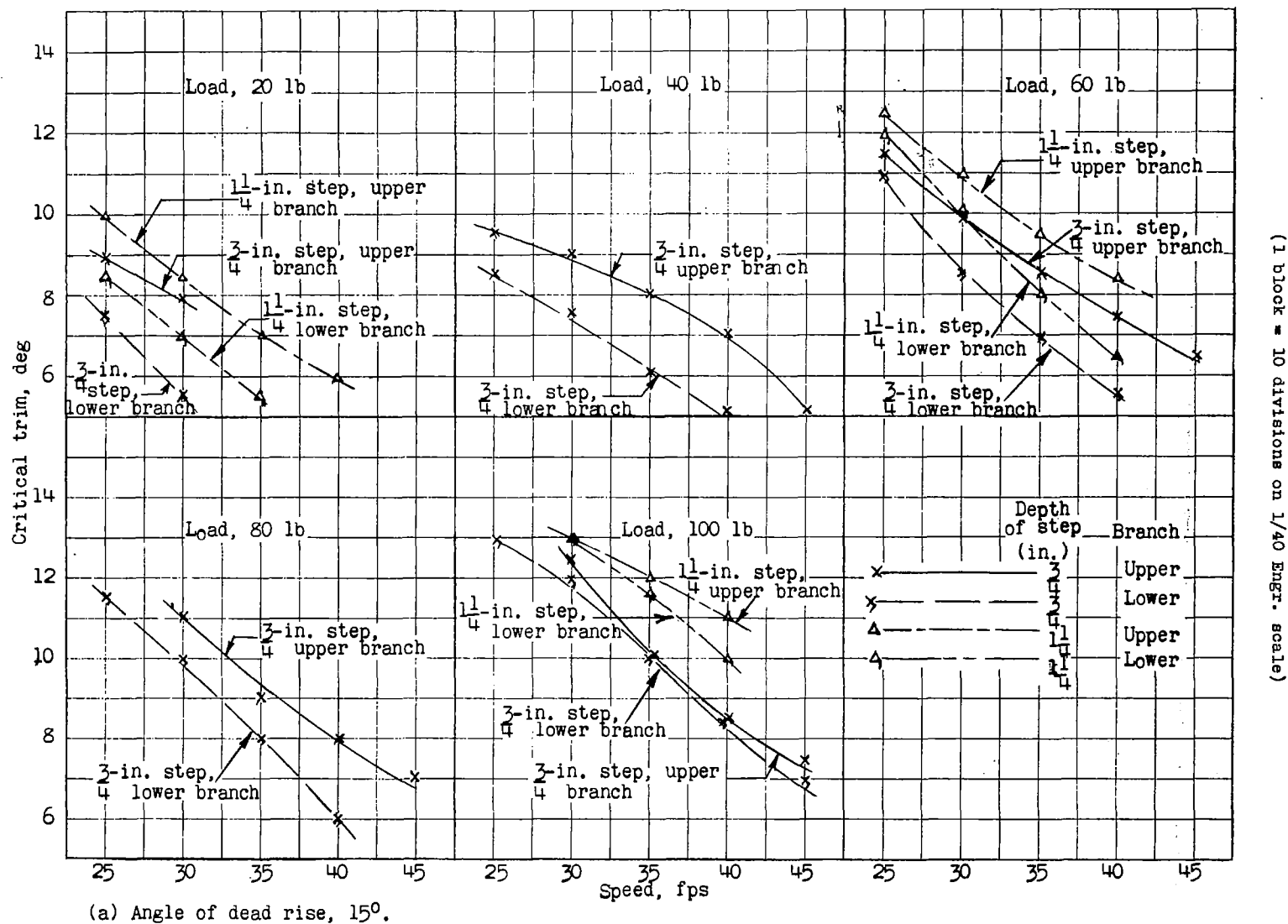


Figure 3.- Variation of critical trim with speed at constant load.

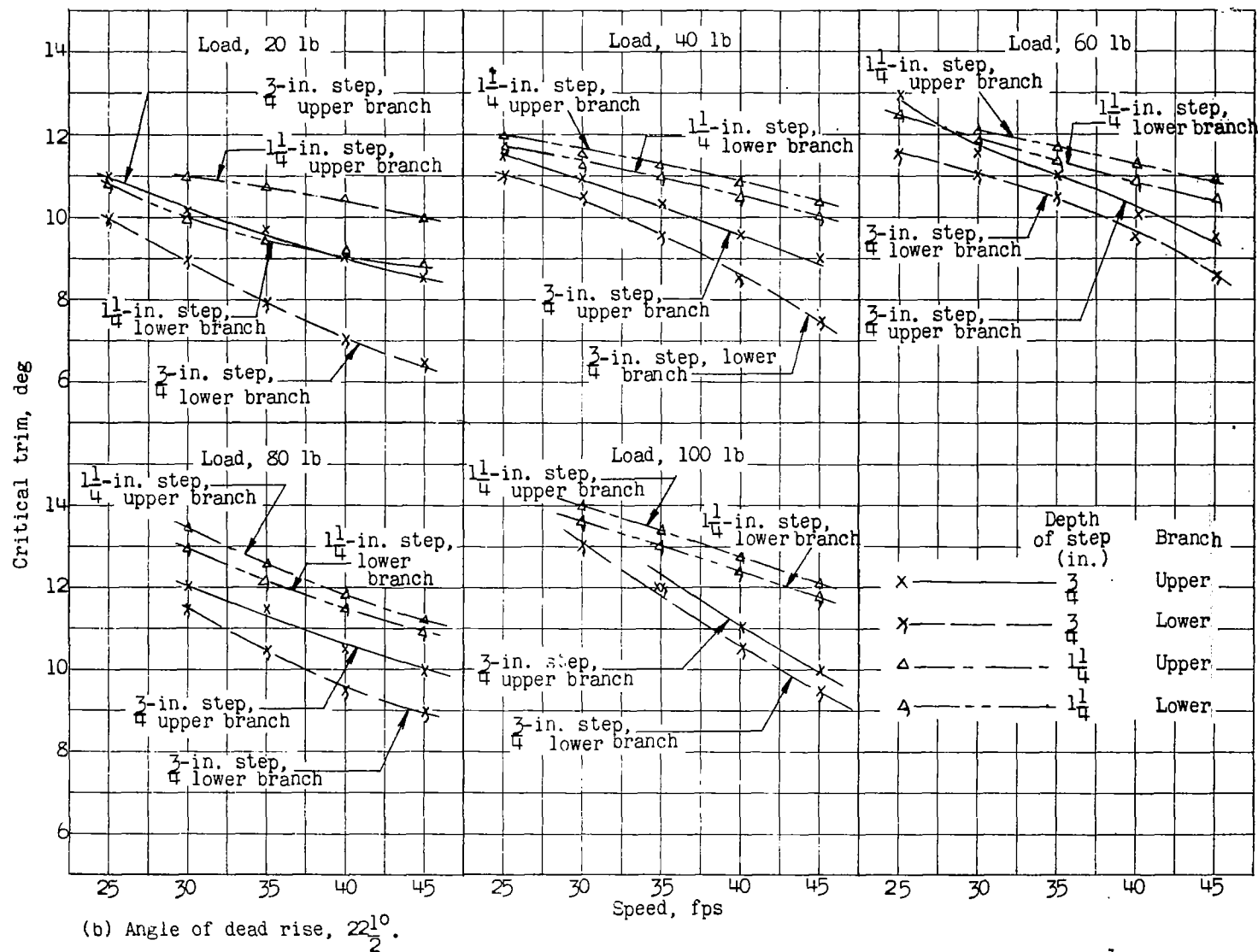
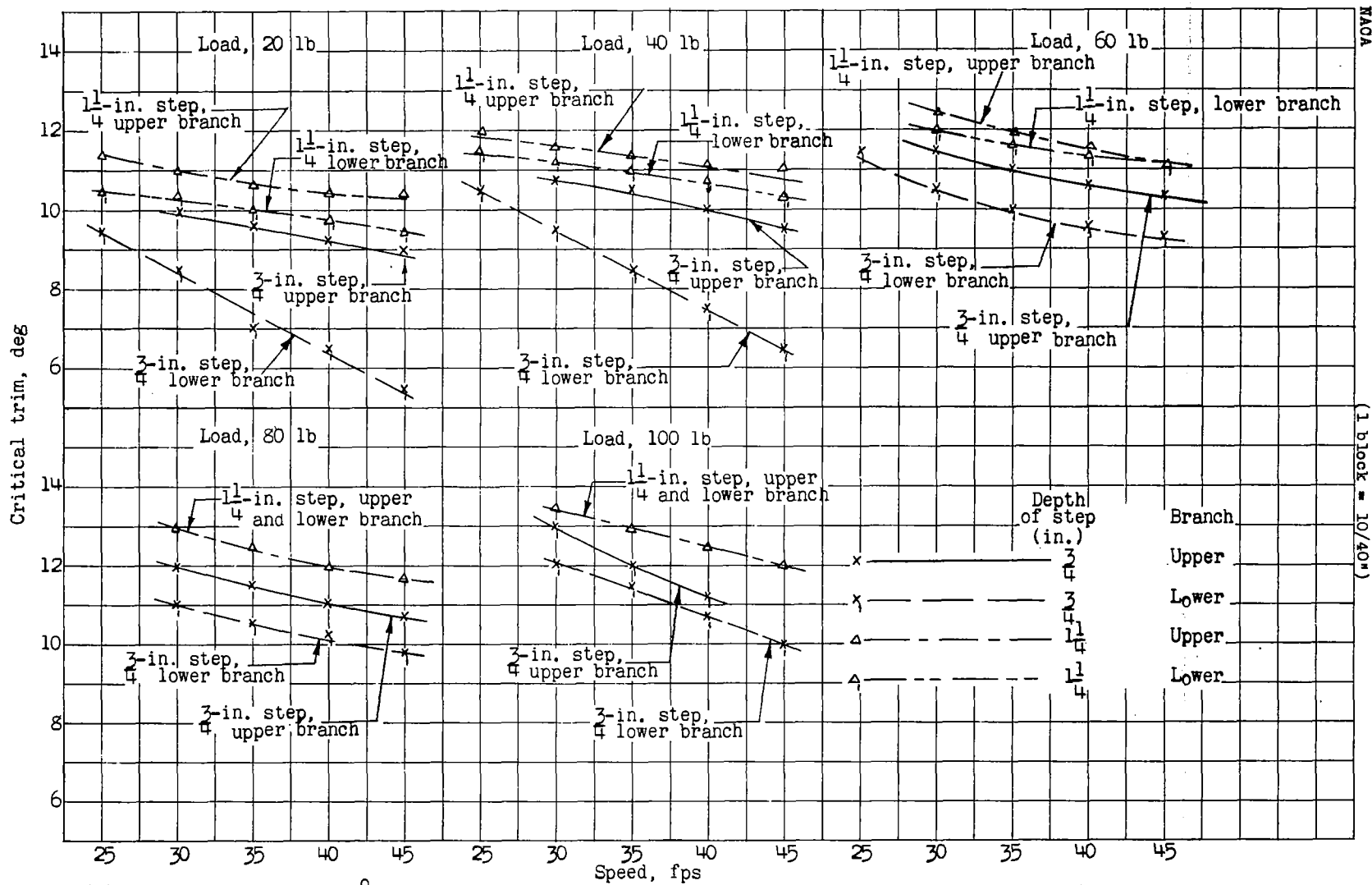
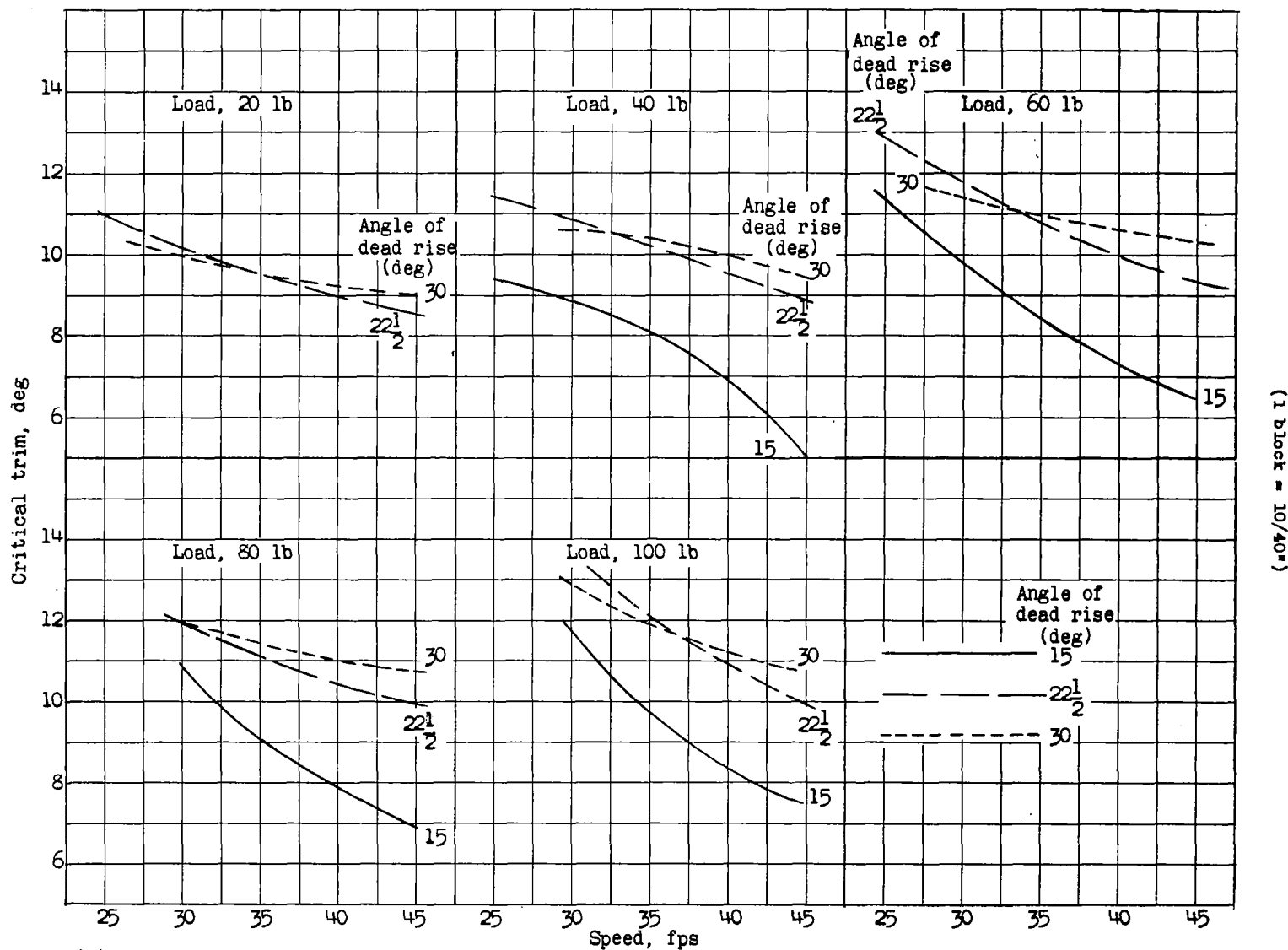


Figure 3.- Continued.



(c) Angle of dead rise, 30° .

Figure 3.- Concluded.



(a) Upper branch; depth of step, 3/4 inch (4.7 percent beam).

Figure 4.- Variation of critical trim with speed, angle of dead rise as parameter. (Faired curves from fig. 3.).

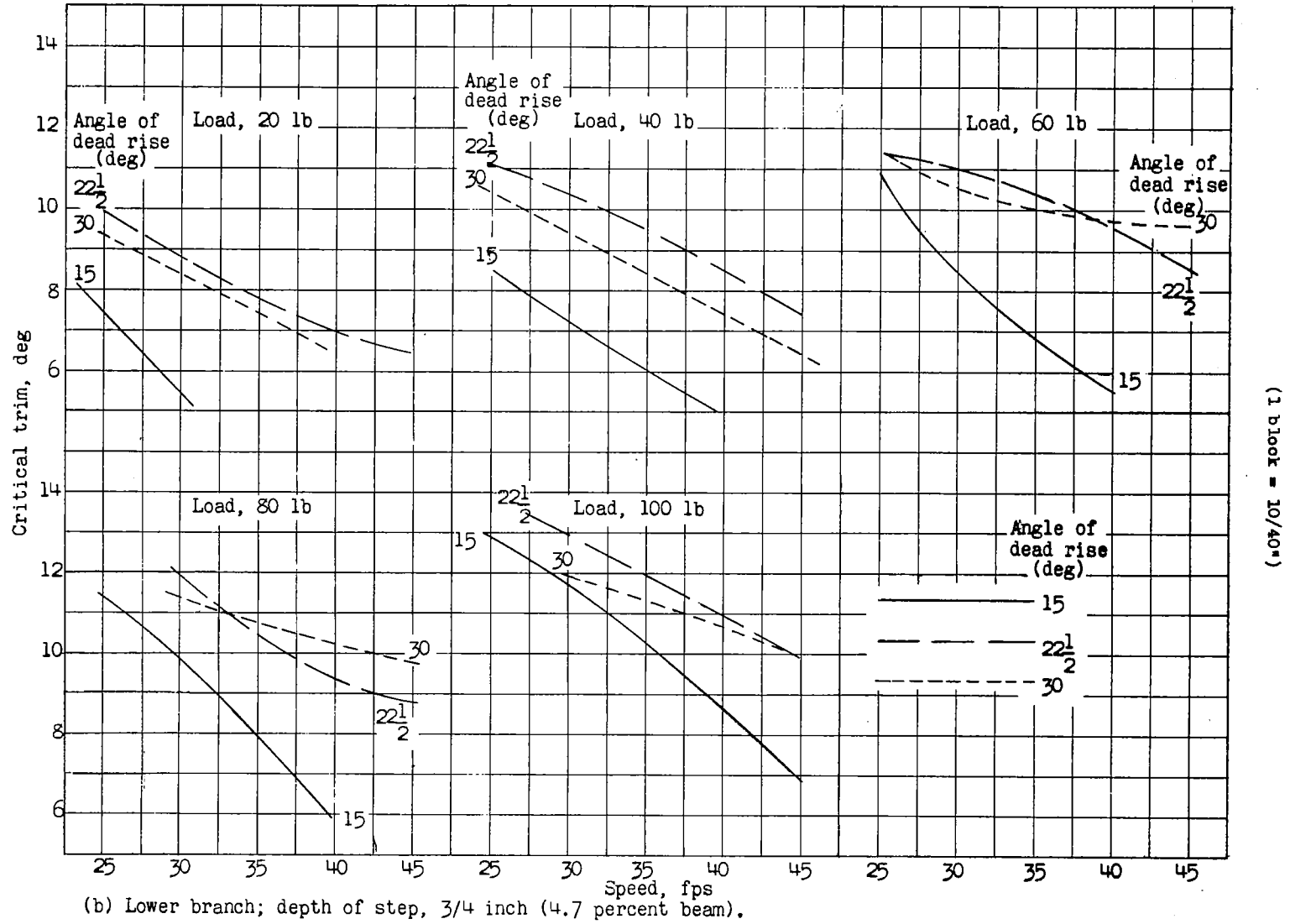
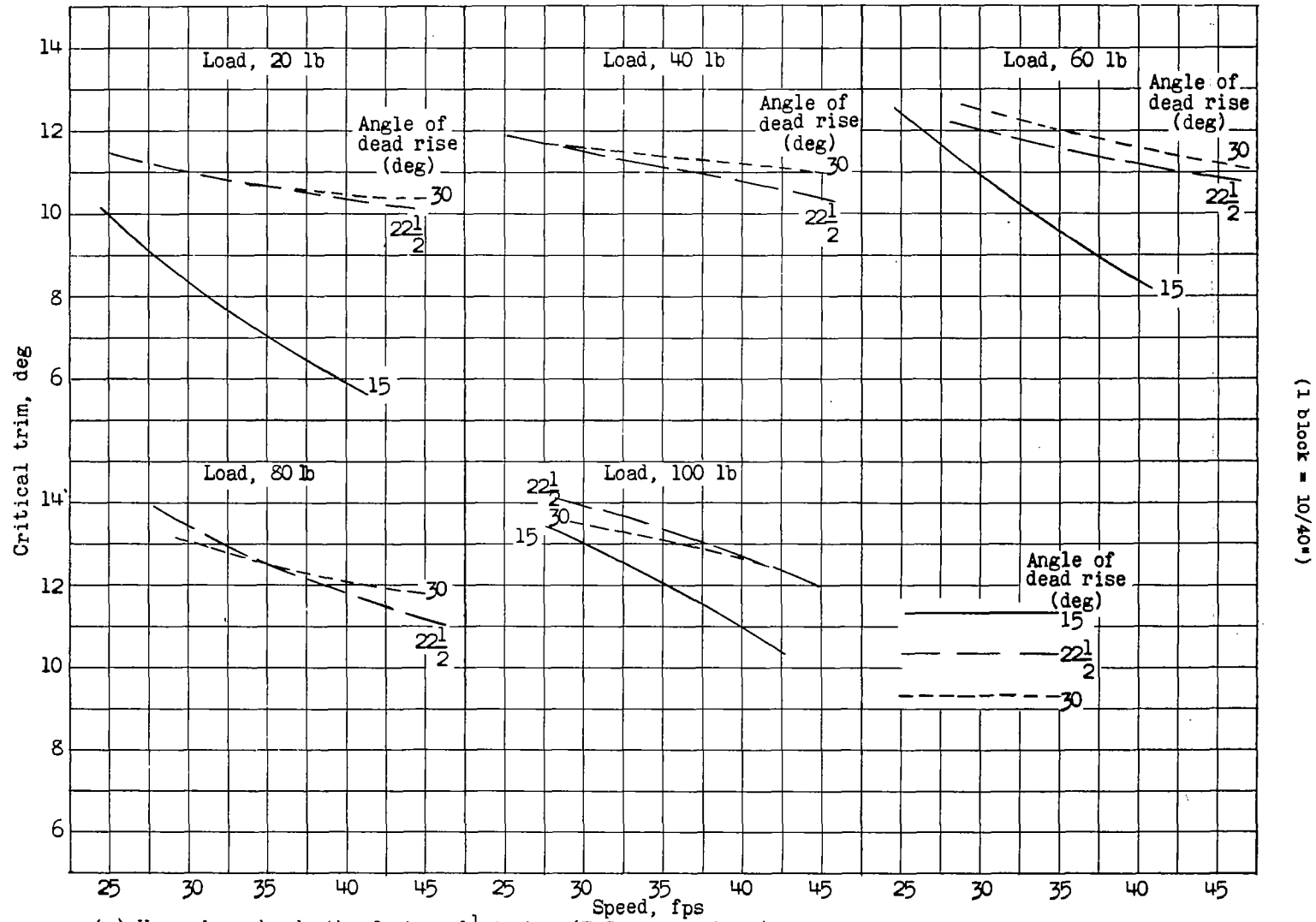
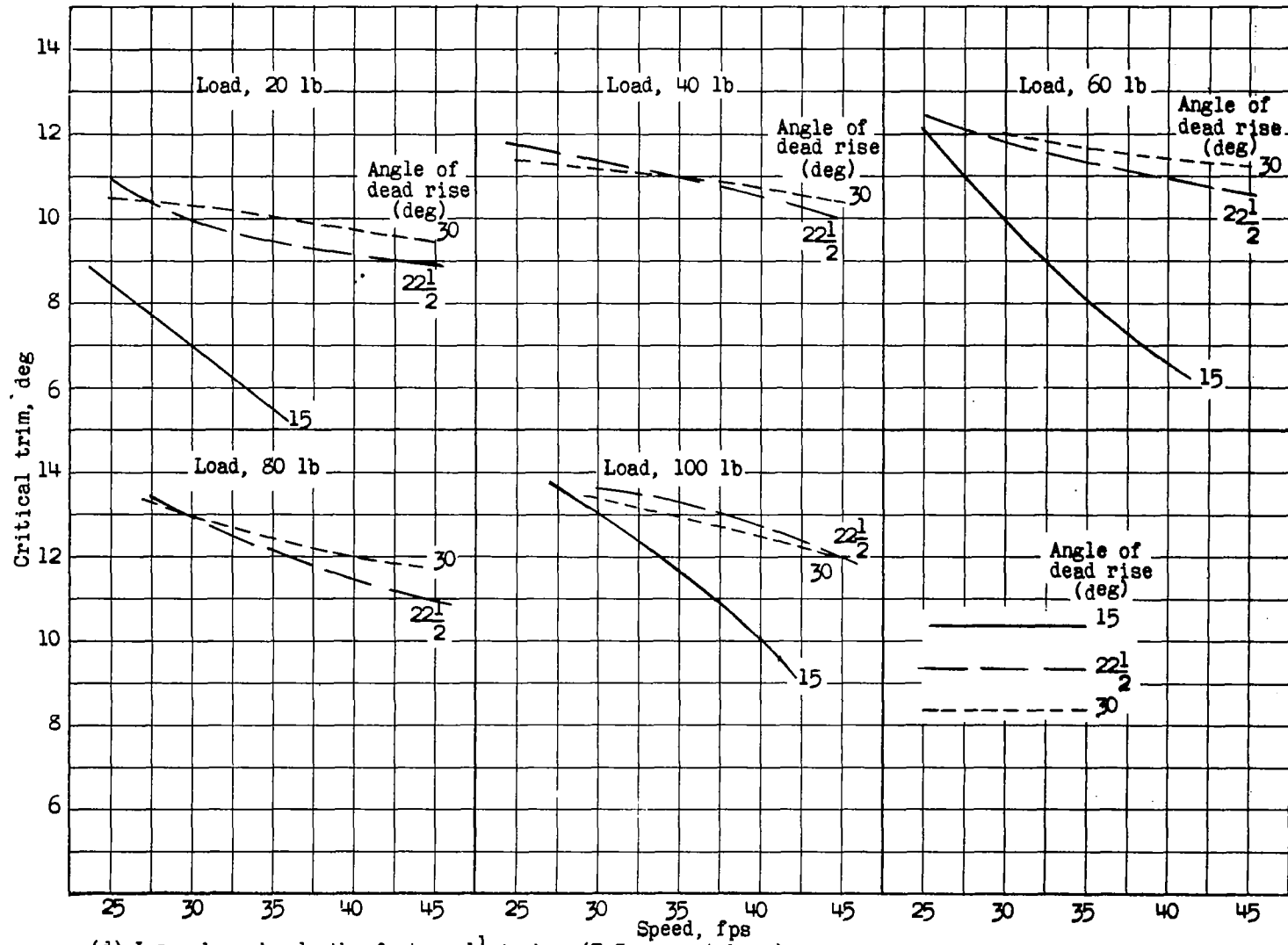


Figure 4.- Continued.



(c) Upper branch; depth of step, $1\frac{1}{4}$ inches (7.8 percent beam).

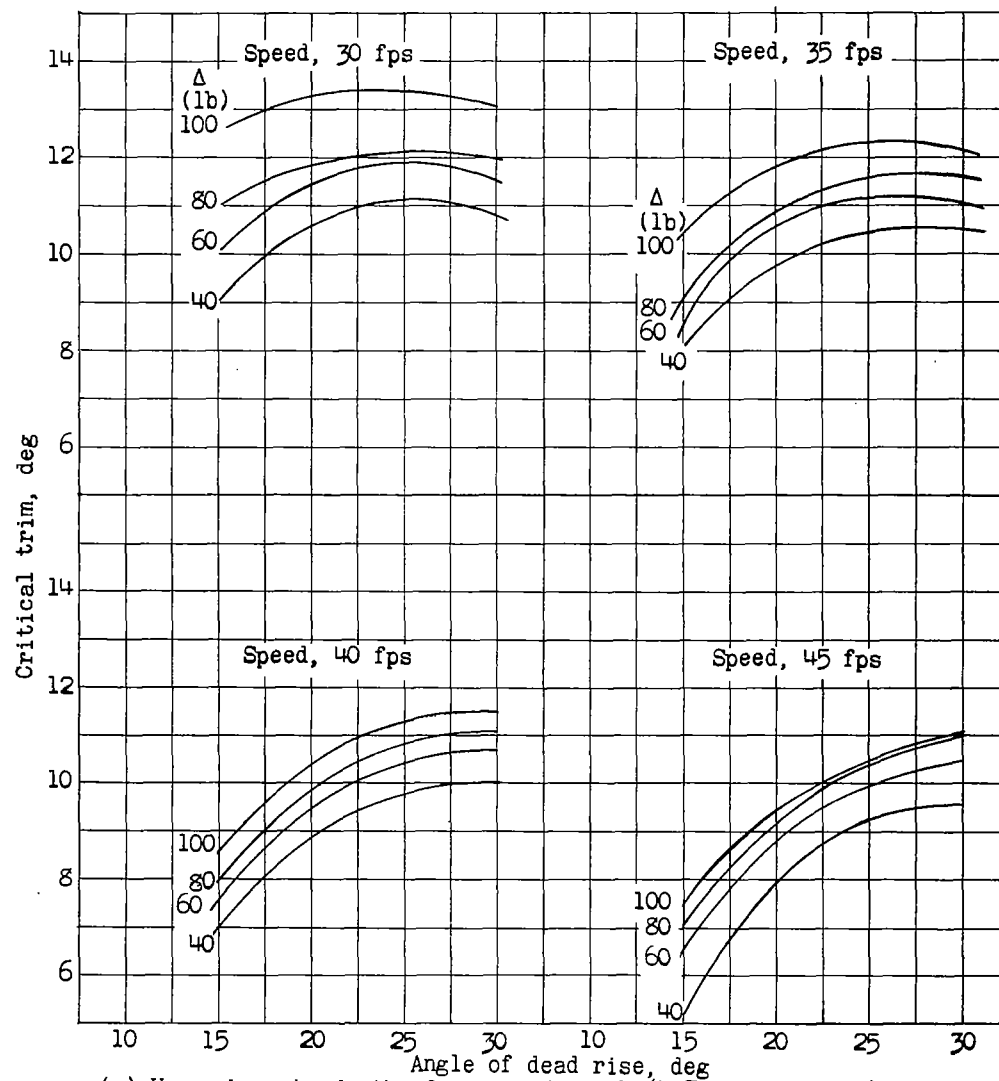
Figure 4.- Continued.



(1 block = 10/40°)

(d) Lower branch; depth of step, $1\frac{1}{4}$ inches (7.8 percent beam).

Figure 4.- Concluded.



(a) Upper branch; depth of step, $3/4$ inch (4.7 percent beam).

Figure 5.- Variation of critical trim with angle of dead rise, load as parameter. (Cross plots of curves of fig. 3.).

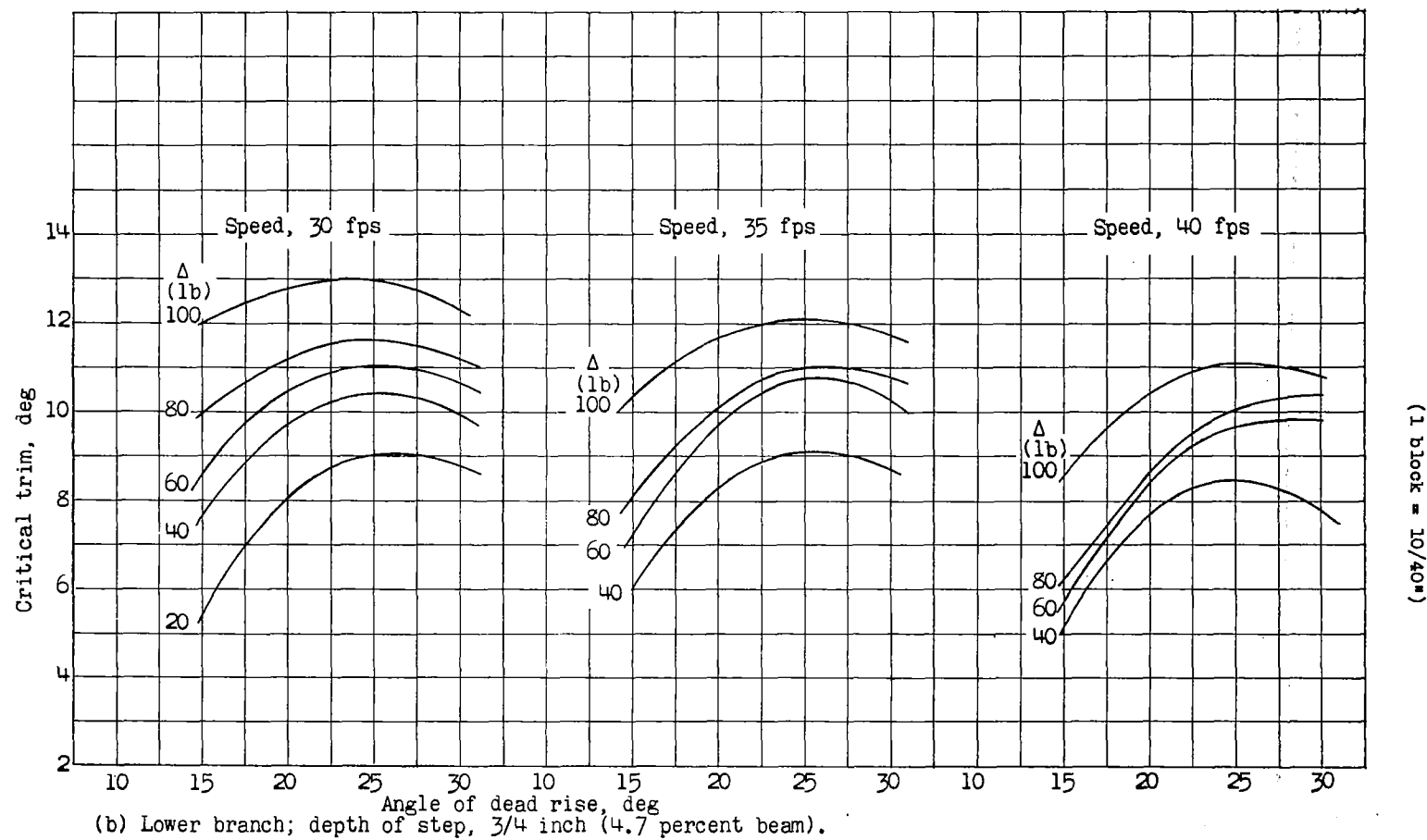
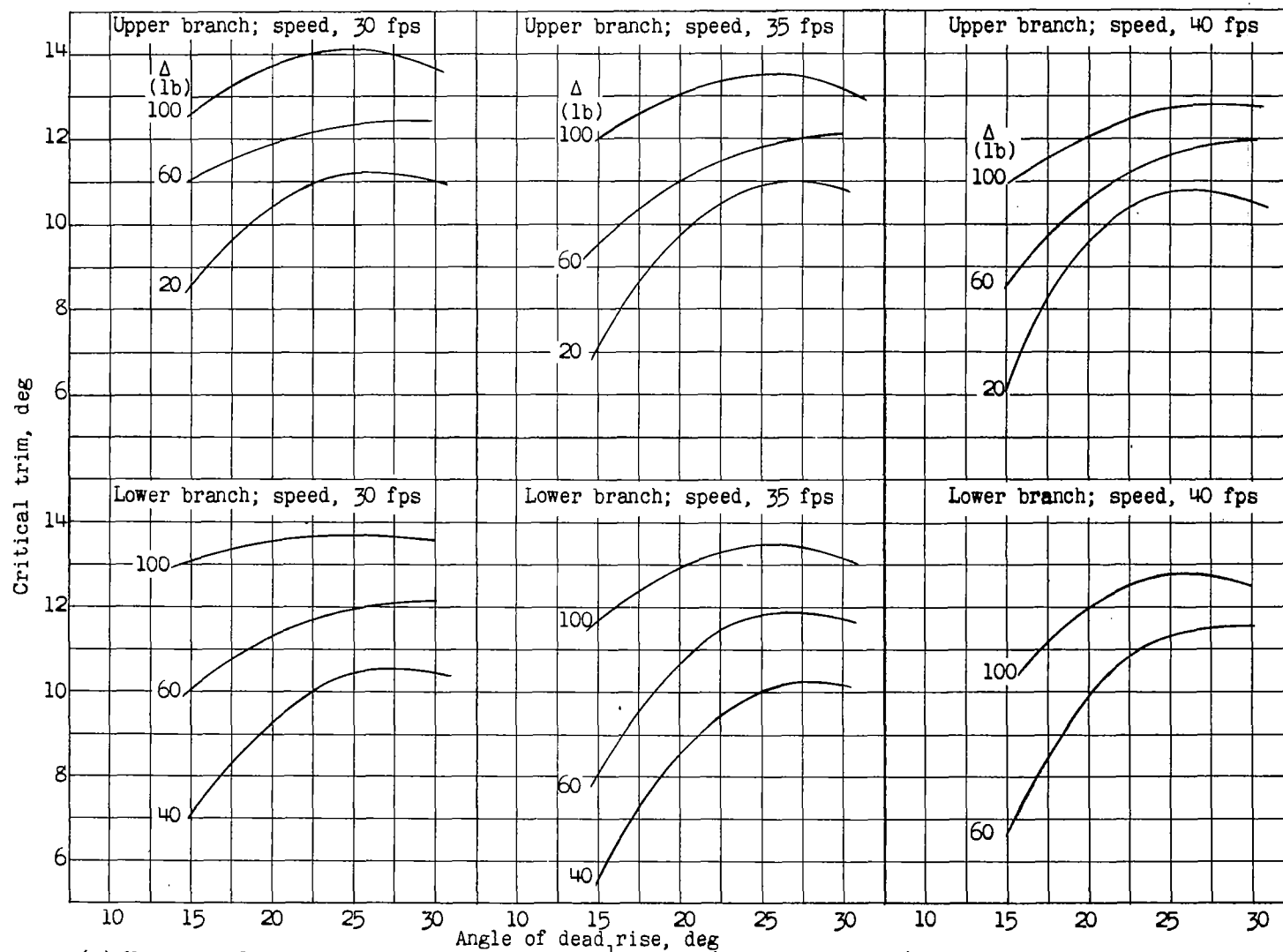


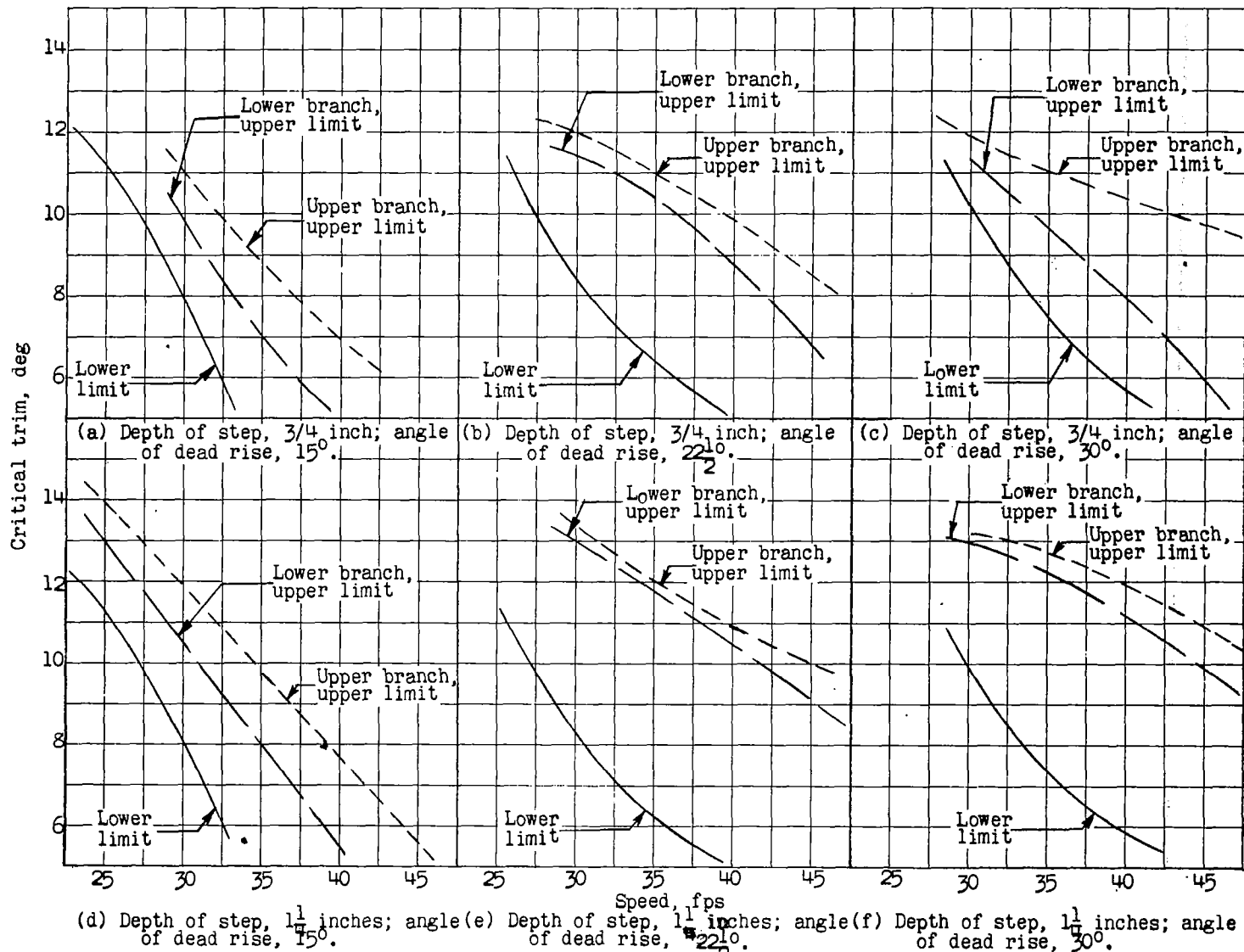
Figure 5.- Continued.



(c) Upper and lower branches; depth of step, $1\frac{1}{4}$ inches (7.8 percent beam).

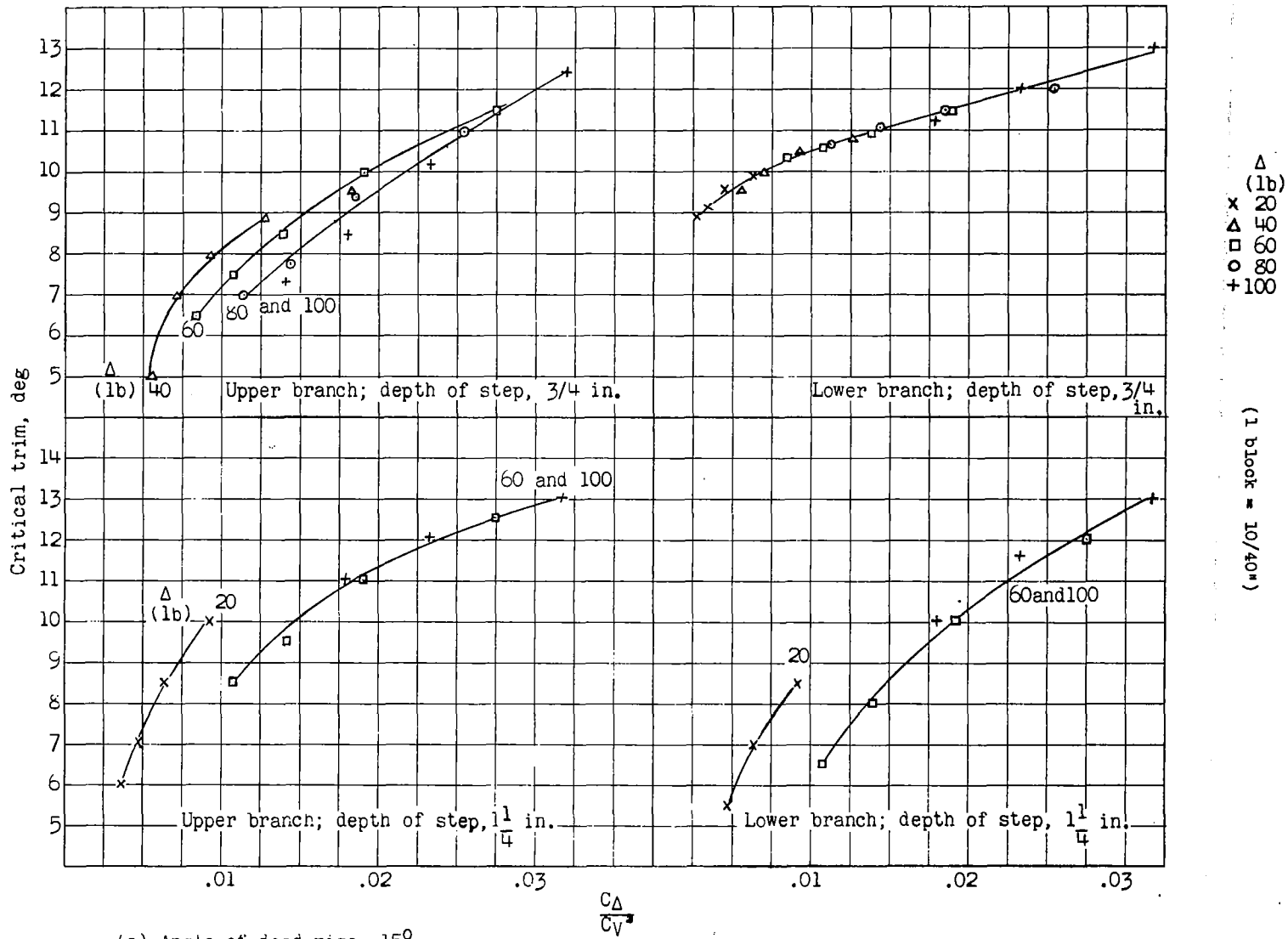
Figure 5.- Concluded.

(1 block = 10/40°)



(1 block = 10/40°)

Figure 6.- Variation of critical trim with speed for three angles of dead rise and two depths of step; allowance made for increase in wing lift with increase in speed. (Curves for lower limit are for forebody alone, from reference 3.).



(a) Angle of dead rise, 15°.

Figure 7.- Variation of critical trim with the coefficient $\frac{C_\Delta}{C_V^2}$ for two depths of step. $\frac{C_\Delta}{C_V^2} = \frac{\text{Load coefficient}}{(\text{Speed coefficient})^2}$.

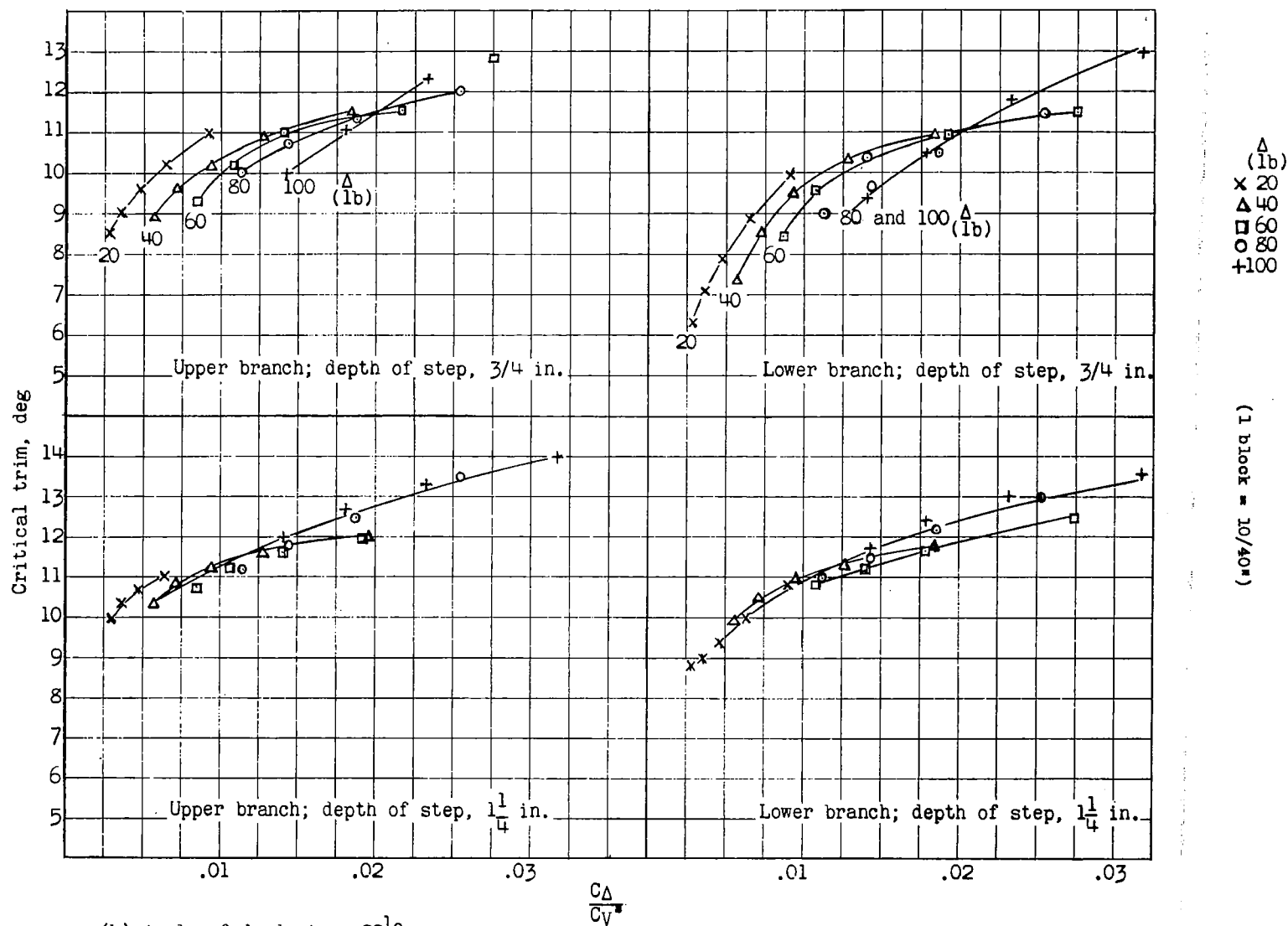
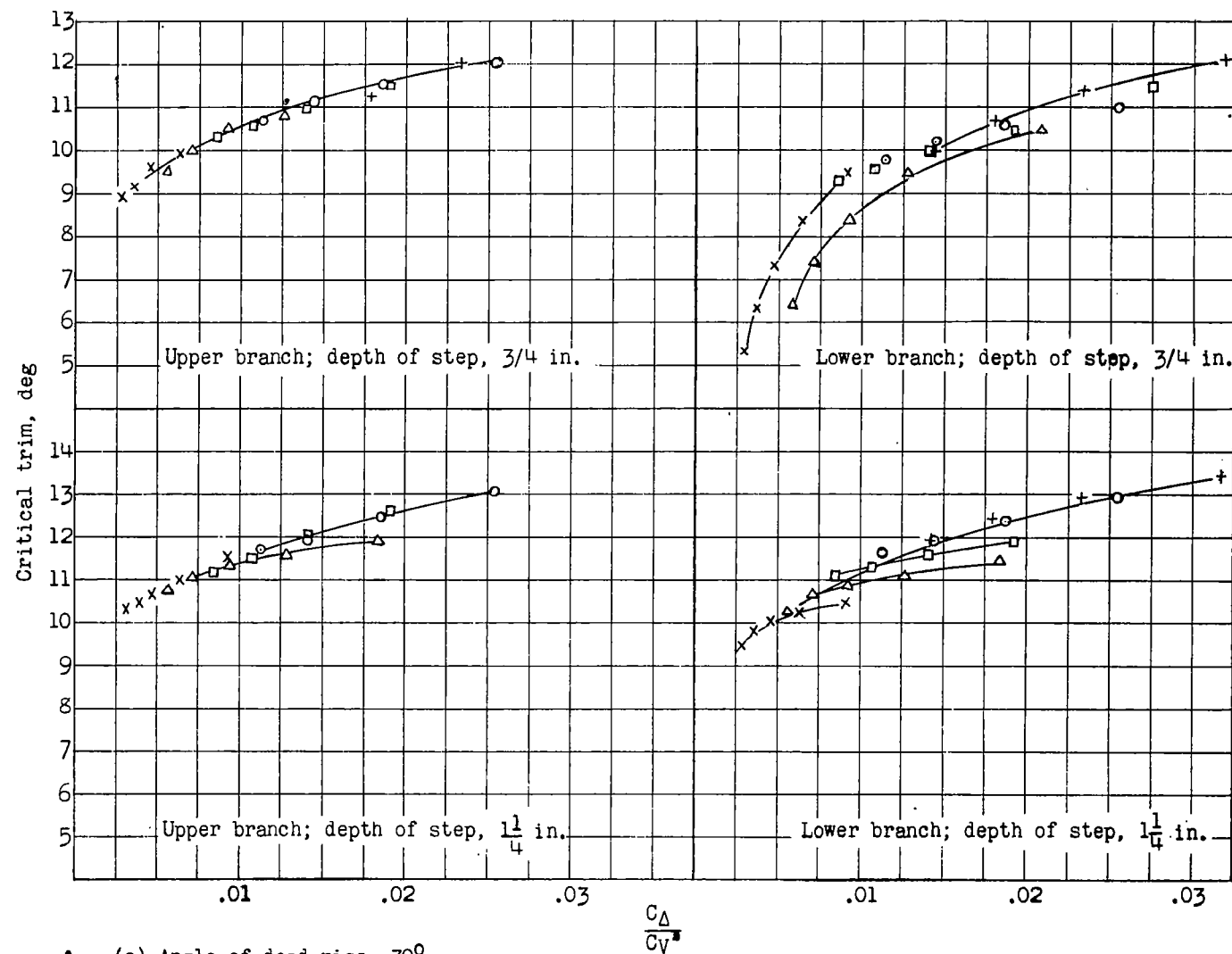


Figure 7.- Continued. $\frac{C_A}{C_V}$ = Load coefficient
(Speed coefficient)



Δ (lb)
 x 20
 △ 40
 □ 60
 ○ 80
 + 100

• (c) Angle of dead rise, 30° .

Figure 7.- Concluded. $\frac{C_{\Delta}}{C_v^2}$ = Load coefficient (Speed coefficient)²

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